Ministry of
Transportation and
Communications

Ontario

MI-91

HL-3 BITUMINOUS MIXES MODIFIED WITH STEEL SLAG FINE AGGREGATE

INTERIM REPORT

MATERIALS INFORMATION
ENGINEERING MATERIALS OFFICE

HL-3 BITUMINOUS MIXES

MODIFIED WITH

STEEL SLAG FINE AGGREGATES
(INTERIM REPORT)

By

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and

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March 1986

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1.0 INTRODUCTION

In March 1983, a proposal was made by the Bituminous Section, Engineering Materials Office to evaluate the use of steel slag fine aggregates in HL-3 mixes.

The objective of the proposal was to "try steel slag fine aggregate with HL-3 stone in order to use an abundant source and to improve the skid resistance of HL-3 mixes (see Appendix A)". The HL-3 modified mixes would be used in lieu of HL-1 for traffic volumes of 5000 to 7000 AADT in selected areas where steel slag fine aggregate is abundant. Expected benefits would be improved stability and friction over normal HL-3 mixes, and cost reductions over HL-1 mixes.

Approval was obtained to construct test sections on two contracts in Hamilton District, Central Region. Five test sections were constructed on Hwy. 55 at Virgil (Contract 82-88), and five sections were constructed on Hwy. 6, the Caledonia Bypass (Contract 82-61). Three HL-3 modified mixes having varying percentages of HL-3 coarse aggregate (from 15% to 45%) and steel slag fine aggregate (from 85% to 55%) were placed on each contract as well as control sections of normal HL-1 and HL-3 mixes.

This report details the various mixes and their performance to date. Interim conclusions and recommendations have been provided.

2.0 TRIAL SECTIONS

The five test sections on Hwy. 55 were constructed in the town of Virgil. The speed limit is 50 km/h, and the surrounding development is both residential and commercial. It is a two-lane highway and there are several intersections within the study area. The AADT for 1983 was 4950. The test sections in Virgil represent a low speed, moderate traffic volume urban area.

Hwy. 6, the Caledonia Bypass, is a rural two-lane highway with a speed limit of 80 km/h and a 1983 AADT of 3000. The highway has moderate grades and curves. Vehicular access to the highway is controlled. Hwy. 6 is representative of a higher speed site.

Each of the test sections are approximately 300 m long, and were constructed using standard techniques. Site plans for Hwy. 55 and Hwy. 6 are shown in Figure 1, with detailed locations of individual test sections in Appendix B.

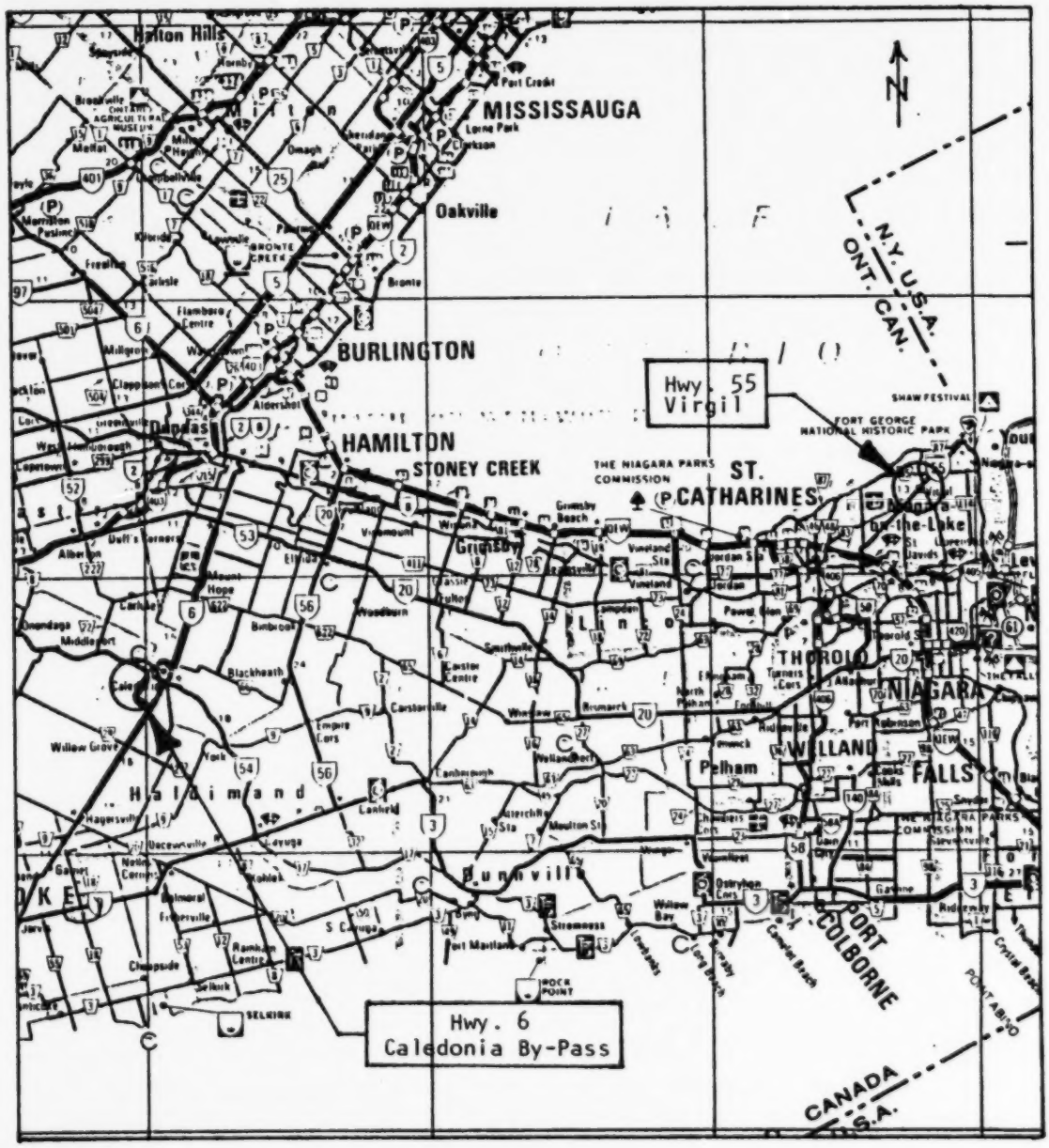


Figure 1: Trial Locations

3.0 Mix Design

Table 1
Mix Designs

Parameter / Test Mix	% Ret'd 4.75 mm	% Pass 4.75 mm	% A.C. Total	% Voids	Flow mm	Stability N	% VMA
Hwy. 6 Cont. 82-61							
1. HL-3 mod. 15/85	14.2	85.8	7.8	2.0	15.2	21 300	14.5
2. HL-3 mod. 30/70	28.7	71.3	6.9	2.2	14.3	18 700	13.3
3. HL-3 mod. 45/55	43.5	56.5	6.2	3.2	14.6	17 100	13.4
4. HL-1 normal	55.1	44.9	5.2	2.7	9.8	16 200	14.3
5. HL-3 normal	45.0	55.0	5.4	3.0	9.0	11 400	15.5
Hwy. 55 Cont. 82-88							
1. HL-3 mod. 15/85	15.0	85.0	8.0	-	-	-	-
2. Hl-3 mod. 30/70	28.4	71.6	7.0	1.0	15.2	22 300	13.2
3. HL-3 mod. 45/55	43.1	56.9	6.0	2.8	15.2	25 700	12.6
4. HL-1 normal	55.0	45.0	5.5	2.3	10.4	14 200	15.2
5. HL-3 normal	45.0	55.0	5.7	3.0	9.7	12 650	15.0

As can be seen from the mix designs (Table 1), stabilities and asphalt content are higher in the HL-3 modified mixes than they are in the HL-1 and HL-3 normal mixes. Extra asphalt cement is required in the modified mixes because of the increased fines content to ensure proper particle coating. The use of steel slag fine aggregate also provides a more absorptive material. The HL-3 modified mixes have higher flows than the HL-1 and HL-3 mixes due to the increased asphalt cement content. The percent voids are relatively low for all mixes because they were set based on visual coating criteria. Percent VMA is generally lower for the HL-3 modified mixes, based on Ontario Provincial Standard Specifications, all HL-3 modified mixes failed to meet VMA specifications by 1.5 to 3.0 percentage points.

The asphalt cement was Gulf 85/100 for all mixes. Table 2 outlines the aggregate type and source for each mix.

TABLE 2

Aggregate Types and Sources

Mix	Fine Aggregate	Coarse Aggregate
Hwy. 6 Cont. 82-61		
1. 2. HL-3 Mod 3.	Dofasco steel slag (unwashed screenings)	Haldimand Quarry HL-3 stone
4. HL-1 Normal	Waterford Sand	Dofasco steel slag
5. HL-3 Normal	Waterford Sand	Haldimand Quarry HL-3 stone
Hwy. 55 Cont. 82-88		
1. 2. HL-3 Mod 3.	Dofasco steel slag (unwashed screenings)	Queenston Quarry HL-3 stone
4. HL-1 Normal	2 parts Queenston Foundry sand with 1 part Queenston Quarry screenings	Dofasco steel slag
5. HL-3 Normal	2 parts Queenston Foundry sand with 1 part Queenston Quarry screenings	Queenston Quarry HL-3 stone

4.0 Visual Observations

All mixes on these two contracts are in good condition. The HL-3 modified mixes, with lower stone content, facilitated handwork in the urban setting and the finished product was good. The following pictures highlight the visual appearance and differences between the mixes.

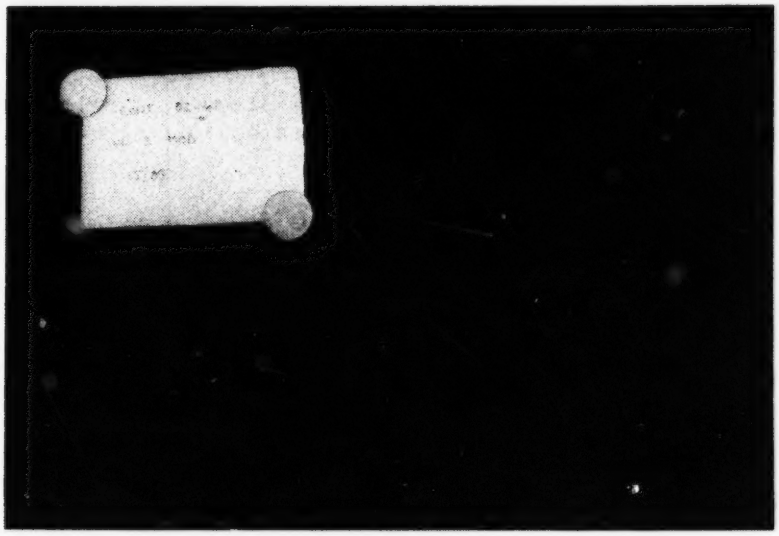


Figure 2: HL-3 Mod. 15/85

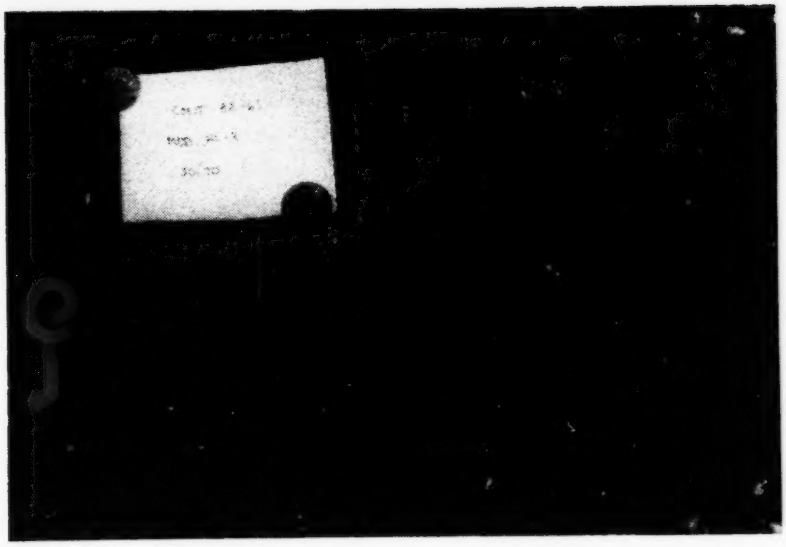


Figure 3: HL-3 Mod. 30/70

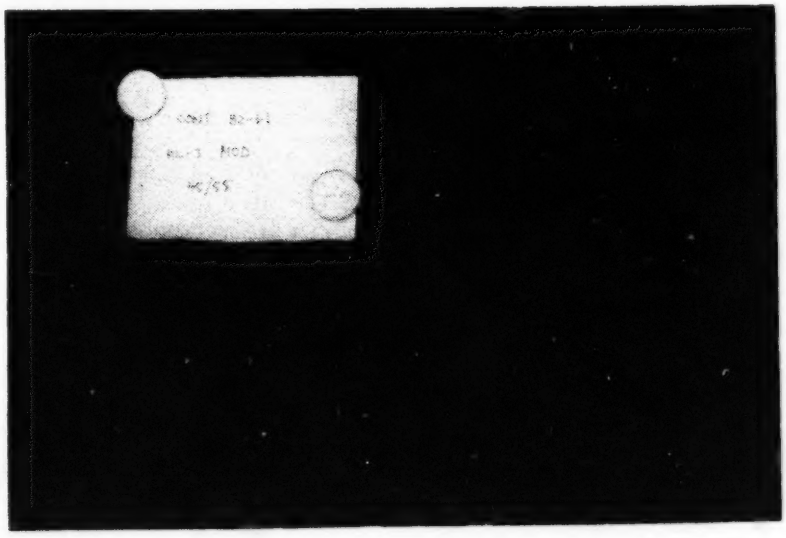


Figure 4: HL-3 Mod. 45/55

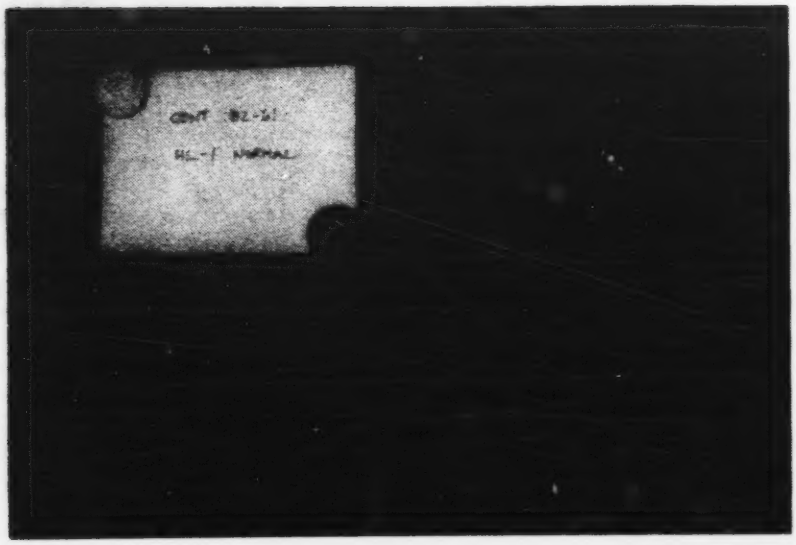


Figure 5: HL-1 Normal

Figure 6: HL-3 Normal

5.0 TEST RESULTS

5.1 Plant Checks and Core Samples

A series of plant checks and core samples were taken on the test mixes and the data obtained is summarized in Table 3.

As can be seen in Table 3, percent compaction for the HL-3 modified mixes are generally in the order of 90%. The HL-3 modified mixes in contract 82-61 exhibit high in place voids. All mixes may be considered to be impermeable to water. The HL-3 modified mixes also have higher stabilities than the HL-1 and HL-3 normal mixes. The higher stability of the HL-3 modified mixes is probably due to the hard, harsh and angular characteristics of steel slag fine aggregates.

For Contract 82-61 there is a large difference between the percent VMA obtained from the plant checks (Table 3) and the VMA obtained in the laboratory mix design. An examination of the respective gradations shows a variation in the steel slag fine aggregate gradation. This change to a coarser gradation would contribute to the low VMA exhibited. Steel slag fine aggregate from the same source was used in Contract 82-88, however, much higher VMA values were obtained comparable to those obtained in the mix design. The gradations were also comparable.

Table 3
Plant Checks and Core Test Results

Sample	% Pass 4.75 mm	% A.C.	Plant Check			Marshall Recompaction of Pavement Sample			Pavement Sample		
	Plant (Cores)	Plant (Cores)	Voids %	% V M A	Stab. N	Voids %	Flow mm	Stab. N	In Place Voids %	% Comp.	Permeability* cm L
Cont. 82-61											
1. HL-3 mod 15/85 a.	89.1 (91.6)	7.35 (6.82)	0.8	9.4	19380	2.0	18.4	21718	11.4	90.3	3.63×10^{-8}
b.	80.6 (85.8)	7.09 (5.99)	0.8	8.4	20395	3.2	14.7	31341	15.4	87.3	-
2. HL-3 mod 30/70	66.0 (60.8)	6.38 (5.56)	0.2	7.5	19269	2.8	22.1	18932	11.0	91.4	1.19×10^{-7}
3. HL-3 mod 45/55	51.4 (55.5)	5.39 (5.15)	2.0	-	17228	3.8	19.2	15929	13.6	91.1	4.81×10^{-7}
4. HL-1 normal	53.3 (56.0)	5.13 (5.16)	2.0	13.7	17407	2.3	12.8	15350	7.2	94.9	1.53×10^{-8}
5. HL-3 normal	51.3 (45.8)	5.39 (4.89)	2.1	-	17228	2.6	11.4	16784	7.4	95.1	7.50×10^{-9}
Cont. 82-88											
1. HL-3 mod 15/85	85.5 (85.6)	7.70 (7.43)	N.M.	19.2	17682	1.6	24.7	16729	8.9	92.6	1.98×10^{-9}
2. HL-3 mod 30/70	70.1 (64.6)	7.04 (6.21)	N.M.	15.5	17800	2.5	27.1	17873	7.3	95.0	1.60×10^{-9}
3. HL-3 mod 45/55	55.4 (57.2)	5.88 (5.69)	N.M.	13.7	20617	4.6	20.8	20248	12.4	91.8	6.15×10^{-9}
4. HL-1 normal	47.9 (41.7)	5.44 (5.08)	1.2	15.1	14940	2.2	16.7	12973	5.8	96.3	9.48×10^{-10}
5. HL-3 normal	54.6 (53.8)	5.73 (5.60)	1.6	14.2	12548	4.0	11.8	11866	8.2	95.5	3.20×10^{-9}

* Air permeability
N.M. not measureable

Note: all are mean values

5.2 FRICTION RESISTANCE

Macrotexture (coarse aggregate projections) and microtexture (sandpaper-like surface) both contribute to friction resistance. A harsh microtexture allows penetration of surface water and breaks the surface water film to achieve good tire contact. Macrotexture is very important, especially at higher speeds, in order to provide bulk water drainage away from the pavement surface. Loss of macrotexture through embedment of coarse aggregate is reduced with increased angularity of the fine aggregate.

It was anticipated that the HL-3 mixes modified with steel slag fine aggregate would improve friction properties with respect to normal HL-3 mixes. To verify if this was correct, a friction survey was conducted on Contract 82-88 in October 1983, and August 1984. For comparative purposes, a friction survey was taken of Contract 82-61 in October 1984. The results of those surveys are shown in Table 4.

Table 4
FRICTION RESISTANCE DATA

MIX TYPE	Hwy. 55, Contract 82-88		Hwy. 6, Contract 82-61
	1983 Friction No. SN 50	1984 Friction No. SN 50	1984 Friction No. SN 80
HL-3 mod 15/85	38 NBL 39 SBL	36 NBL 39 SBL	40 NBL 40 SBL
HL-3 mod 30/70	40 NBL 41 SBL	35 NBL 40 SBL	39 NBL 39 SBL
HL-3 mod 45/55	39 NBL 38 SBL	37 NBL 38 SBL	39 NBL 38 SBL
HL-3 Normal	30 NBL 32 SBL	25 NBL 28 SBL	39 NBL 40 SBL
HL-1 Normal	36 NBL 36 SBL	36 NBL 36 SBL	39 NBL 42 SBL

Table 4 indicates that the HL-3 modified mixes compared favourably with the HL-1 normal mixes after one and two years. In Contract 82-88, the HL-3 modified mixes performed significantly better than the HL-3 normal mix. In Contract 82-61, all friction results were comparable after two years.

All mixes on Contract 82-61 performed well. The good friction resistance of the HL-3 normal mix may be attributed to the excellent aggregate abrasion value (AAV) of 8.82 and moderate polished stone value (PSV) 48 of the coarse aggregate. Typically, quarried limestone has aggregate abrasion values of 12 and do not perform well as a resistant aggregate (1).

As mentioned, macrotexture is very important at higher speeds. However, in Contract 82-61, the mix containing 15 percent coarse aggregate offers limited macrotexture, yet still exhibits good friction resistance at 80 km/h. It appears that the harsh microtexture of the modified mixes (55, 70 and 85 percent fines) compensated for the lack of macrotexture and produced good friction results. Further friction measurements will be necessary to monitor the effectiveness of steel slag fines in high speed applications, however, this confirms that a harsh microtexture is desirable at all speeds.

On Contract 82-88, the quarried limestone (HL-3 stone) has a poor AAV of 13.7, and a moderate PSV of 50. The low resistance to abrasion and moderate PSV combine to give the aggregate poor frictional qualities. This poor resistance to abrasion and polishing is evident in the HL-3 normal mix, where in 1983, the mix had lower friction numbers, and in 1984, the friction resistance had declined significantly in relation to other mixes.

On the same contract, the HL-3 mixes modified with steel slag fine aggregates exhibited excellent friction numbers although the coarse aggregate is the same as that used in the HL-3 normal mix. Factors which contributed to the excellent friction qualities of the modified mixes are attributed to the increased harshnes of the pavement matrix (steel slag fines). The harsh microtexture of the matrix allows penetration of the thin film of water on the pavement surface, which is desirable for good tire to pavement contact.

6.0 COSTS

The costs for each of the trial mixes used on Contract 82-88 were estimated on a price per tonne basis by the Estimating and Claims Office, MTC and are listed in Table 5. However, since the bulk relative density (BRD) of the mixes vary depending on the quantity of steel slag fines used, a cost comparison based on a 40 mm lift is also included. The prices listed in Table 5 are inclusive of all labour, equipment and materials to perform the work.

The HL-3 normal mix is the least expensive mix, while the HL-3 modified with 70 and 85 percent steel slag fines are more costly because of their higher asphalt cement contents. The larger quantity of asphalt cement required in the higher percentage steel slag fine mixes offset any savings gained in using a lower priced coarse aggregate. The HL-1 normal mix and the HL-3 mix modified with 55 percent steel slag fines are roughly equivalent in costs.

In terms of cost effectiveness, based on friction resistance, the HL-1 normal and HL-3 modified with 55 percent steel slag fines offer the same value. These two mixes cost the same and have comparable friction resistance values. The remaining two HL-3 modified mixes (70 and 85 percent steel slag fines) offer good friction resistance, however, their cost is significantly higher than the HL-1 mix. The HL-3 modified mixes are more expensive than the HL-3 mixes but perform siginificantly better.

TABLE 5

ASPHALT MIX UNIT COSTS
CONTRACT 82-88

MIX TYPE	B.R.D. ** t/m^3	% A.C.	COST PER TONNE	COST PER m^2*
HL-3 mod 15/85	2.700	8.0	$ 50.00	$ 5.31
HL-3 mod 30/70	2.704	7.0	$ 47.00	$ 5.08
HL-3 mod 45/55	2.654	6.0	$ 43.00	$ 4.56
HL-3 normal	2.374	5.7	$ 39.00	$ 3.70
HL-1 normal	2.614	5.5	$ 44.00	$ 4.60

* 40 mm mat thickness

** Bulk Relative Density

7.0 CONCLUSIONS

1. The use of steel slag fine aggregate can significantly improve the friction resistance of HL-3 mixes, particularly when the coarse aggregate has poor frictional properties.

2. In contract 82-88, the HL-3 modified mixes performed significantly better, after one and two years, than the HL-3 normal mix and compared favorably with the HL-1 normal mix.

3. In contract 82-61 all friction results were comparable after two years.

4. Construction procedures using the modified mixes remained unchanged. Handwork was facilitated by use of mixes with a lower percentage retained on the 4.75 mm sieve.

5. There are no cost reductions over standard HL-1 mixes by the substitution of steel slag fine aggregate mixes. The use of steel slag fine aggregate in HL-3 mixes necessitates additional asphalt cement and increases the cost.

6. All steel slag fine aggregate mixes have excellent stability, but exhibit high pavement voids and low compaction.

7. Variability of the gradation of steel slag fine aggregate leads to unpredictable VMA results.

8.0 RECOMMENDATIONS

1. Yearly friction measurements should be taken on Contracts 82-61 and 82-88 to monitor the friction resistance of the various mixes.

2. If additional friction resistance testing on Hwy. 6 Caledonia, shows no substantial deterioration, it is recommended that a high speed (80+ km/h), high volume (ie. 7000 AADT) trial section be constructed.

3. The MTC should examine allowing the contractor, in restricted circumstances, the option of using HL-3 modified with steel slag fine aggregate in lieu of HL-1.

   A special provision would allow the contractor to excercise this option, at his own cost. The warrant for use would be when the AADT per lane does not exceed 3500 and the posted speed limit does not exceed 60 km/h.

4. Any further construction using HL-3 modified mixes with steel slag fine aggregate should be monitored to provide additional information on the use of this type of mix.

5. Gradation requirements should be specified for steel slag fine aggregate in order to reduce the degree of variability in their gradations.

6. The possibility of fortifying the fine aggregate portion of an HL-3 mix with steel slag fine aggregates should be studied (i.e. 2 parts sand to 1 part steel slag fines). The expected results would be increased friction resistance over HL-3 normal mixes, and cost reductions over HL-1 mixes.

REFERENCES

1. Rogers, C., "Search for Skid Resistant Aggregates in Ontario", Ministry of Transportation and Communications, Ontario, Engineering Materials Office.

2. Kamel, N., Musgrove, G.R., and Rutka, A., "Design and Performance of Bituminous Friction Course Mixes" Gulf Canada Limited, Research and Development Department, Sheridan Park, Ontario, Canada.

APPENDIX A

Ministry of Transportation and Communications
Ontario

Memorandum

To: Mr. J. Smrcka,
Manager,
Construction Office,
Central Region.

Attention:

From: Bituminous Section,
Downsview.

Date: 83 03 31

Our File Ref.

In Reply to

Subject: Use of Steel Slag Fines
in an
HL-3 Mix - Trial Sections 1983

Attached you will find a proposal to utilize steel slag fines in an HL-3 mix. This work has been approved by T.G. Smith. The two contracts selected, Contracts 82-61 and 82-88, are in the Hamilton District close to the sources and should work out quite well. Would you proceed with discussions with the Contractors and if any additional costs are involved, the additional work should be handled by separate D4S, on each contract.

J. I. McDougall,
Bituminous Engineer,

for: D. F. Lynch,
Head, Bituminous Section.

DFL:JIM:mv
Attach.

cc: R. Black
G.A. Wrong

STEEL SLAG FINE AGGREGATE IN HL-3 MIX - TRIALS 1983

PROPOSAL

It is proposed to try steel slag fine aggregate with HL-3 stone in order to use an abundant source and to improve the skid resistance of HL-3 mixes.

METHOD

The main forté of the steel slag fines in an HL-3 mix will probably be in an increased skid resistance value for low traffic speed areas. The plan is to run three different sand stone mixes to capture any trends that may develop. A control(s) mix of HL-3 (& HL-1) should also be available for comparison and evaluation.

TEST SITES

Two contracts in your area are likely candidates to fullfil the project requirements:

Contract 82-61; Hwy. #6, Caledonia By-pass;
Contractor - Standard Paving

Contract 82-88; Hwy. #55, Niagara-on-the-Lake;
Contractor - Steed & Evans

The Hwy. #6 project would give us a higher speed site and the Hwy. #55 site would simulate a slower speed (built up area) test site.

TEST MIXES

Mix	Type	By Volume Coarse Agg.	Fine Agg.
1	HL-3 Mod.	30% LS	70% SS
2	" "	45% LS	55% SS
3	" "	60% LS	40% SS
4	HL-3	45% LS	55% NS*
5	HL-1	50% SS (or TR)	50% NS*

Legend

LS - Limestone
SS - Steel Slag
NS - Natural Sand
* May include screenings
TR - Trap Rock

TRIAL BATCHES

The Contractor shall demonstrate his ability to produce the required mix before the initial placement of the test section on the contract. This will be done by mixing a minimum of two batches (of the size that will be used throughout the work), of the desired mix at the plant where it will be sampled and tested. This testing will take approximately two hours after which time the Contractor may start placing the mix on the road, providing the test is satisfactory. If the test mix is unsatisfactory, corrections shall be made and the testing procedure repeated.

SELECTION OF TEST AREA

These mixes should be located on a tangent section without any stop/type conditions within 500 m of the areas. They should be placed in a section where they would probably receive equal traffic wear. (Avoid areas near tapers, etc.).

The length of these test sections should be a minimum of 300 metres for each one.

TESTING

Extra material shall be sampled for any future laboratory work (3 extra bags of each material).

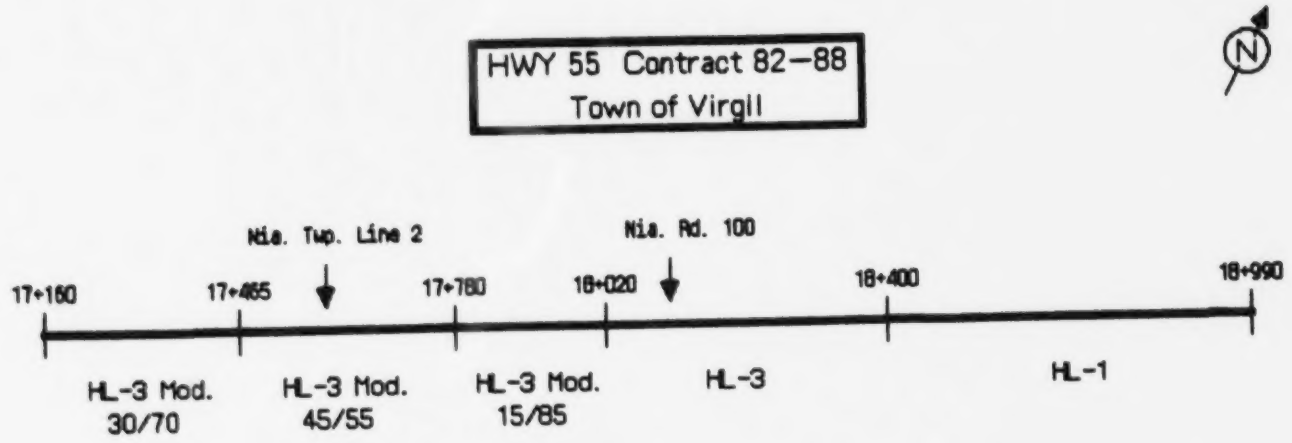
The HL-3 and HL-1 coarse aggregates shall be tested for Polished Stone Value and Aggregate Abrasion Value.

Initial and annual skid resistance monitoring will be performed by the Pavement Management Section in order to assess the project.

The voids in pavement and percent compaction shall be determined. This type of pavement evaluation testing will be programmed for the following periods, initially, one year, three year and for the fifth year of the pavement service.

APPENDIX B

HWY 55 Contract 82–88
Town of Virgil



HWY 6 Contract 82–61
Caledonia By–pass